

FINAL REPORT

Laboratory Simulations of Martian and Venusian Aeolian Processes

NC-2-346
Invention Statement
on Pg. 6
Submitted to
Director, University Affairs Office
and

Chief, Planetary Systems Branch
Technical Monitor: Dr. Bruce Smith

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California 94035

Principal
Investigator:


Signature
Ronald Greeley, Professor
Department of Geology
Arizona State University
Tempe, AZ 85287-1404

1 May 99
Date

Phone: (602) 965-7045
Fax: (602) 965-8102

RECEIVED
JUN 18 1999

rec'd.
JUN 14 1999
cc: 202A-3

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OBJECTIVE

The objective of this work was to conduct research in the Planetary Aeolian Facility (PAF) at NASA-Ames Research Center as a laboratory for the planetary science community and to carry-out experiments on the physics and geology of particles moved by winds, and for the development of instruments and spacecraft components for planetary missions.

1.0 Introduction

With the flyby of the Neptune system by Voyager, the preliminary exploration of the Solar System was accomplished. Data have been returned for all major planets and satellites except the Pluto system. Results show that the surfaces of terrestrial planets and satellites have been subjected to a wide variety of geological processes. On solid-surface planetary objects having an atmosphere, aeolian processes are important in modifying their surfaces through the redistribution of fine-grained material by the wind. Bedrock may be eroded to produce particles and the particles transported by wind for deposition in other areas. This process operates on Earth today and is evident throughout the geological record. Aeolian processes also occur on Mars, Venus, and possibly Titan and Triton, both of which are outer planet satellites that have atmospheres.

Mariner 9 and Viking results show abundant wind-related landforms on Mars, including dune fields and yardangs (wind-eroded hills). On Venus, measurements made by the Soviet Venera and Vega spacecraft and extrapolations from the Pioneer Venus atmospheric probes show that surface winds are capable of transporting particulate materials and suggest that aeolian processes may operate on that planet as well. Magellan radar images of Venus show abundant wind streaks in some areas, as well as dune fields and a zone of possible yardangs.

The study of planetary aeolian processes must take into account diverse environments, from the cold, low-density atmosphere of Mars to the extremely hot, high-density Venusian atmosphere. Factors such as threshold wind speeds (minimum wind velocity needed to move particles), rates of erosion and deposition, trajectories of windblown particles, and aeolian flow fields over various landforms are all important aspects of the problem. In addition, study of aeolian terrains on Earth using data analogous to planetary data-collection systems is critical to the interpretation of spacecraft information and places constraints on results from numerical models and laboratory simulations.

2.0 Summary of use of PAF

2.1 Modeling the Mars Pathfinder (MPF) site *Ronald Greeley, Arizona State University*

Exploratory experiments were conducted to model aeolian deposition and deflation over a model of the Mars Pathfinder landing site in order to determine the feasibility of such experiments to shed light on the surficial geological history of this region of Mars.

Preliminary experiments suggest that the site is predominantly deflational, and were reported at the Fall meeting of the American Geophysical Union, December, 1998.

2.2 Mars Atmospheric Stability experiments *Bruce White, University California/Davis*

The effects of Martian atmospheric stability is currently being investigated in the Mars Surface Wind Tunnel. The thermally unstable boundary layer is generated in the wind tunnel under Martian conditions by heating the surface. Preliminary results indicate that the resulting instability enables particle threshold to occur at lower wind speeds than previously suspected. Surface heat may also have an effect on reducing inter-particle forces of fine-grained material.

2.3 Mars Pathfinder ASI/MET wind sensor tests *Alvin Seiff, San Jose State University*

The Mars Pathfinder spacecraft carried a hot-wire wind sensor capable of measuring winds between 1 and 50 meters per second. Engineering and flight models were tested and calibrated in the Mars Surface Wind Tunnel under a variety of atmospheric desitites and wind velocities. The laser doppler velocimeter was used to measure the wind speed. Tests were conducted in both Earth air and Martian CO₂ environments. As part of the tests, a turntable system was developed to simulate wind direction changes in the wind tunnel by rotating the sensor through known angular increments. Results from these tests are currently being used to analyze the Pathfinder data.

2.4 MVACS wind sensor testing *David Crisp, Jet Propulsion Laboratory*

The Mars Surveyor 98 Lander (MVACS) carries two wind sensors, one of which is capable of measuring wind velocity and direction and another for measuring wind velocity only. Both were tested at a variety of pressures, wind speeds, and atmospheric compositions in MARSWIT. These tests included the engineering models and flight units. Test were run in both Earth air and CO₂ and utilized the same turntable as the Mars Pathfinder wind sensor. The tested wind velocities ranged between 1 and 100 meters per second.

2.5 Martian Dust Threshold and Flux experiments: *Ronald Greeley, Arizona State University*

The Mars Surface Wind Tunnel is currently being used to understand the behavior of dust (1-2 microns) under Martian conditions. Initial results on threshold have been presented at various meetings (LPSC, AGU, DPS), and published. A new experiment test section was developed to determine flux. It consists of 24-aluminum disks that can be removed using a cam mechanism. Carbondale Red Clay is aerodynamically settled onto the test section. The disks are removed, weighed, and returned to the test bed. After the run, the disks are removed and weighed; flux is determined as the difference in weight before and after the run, divided by the run time. The experiments are conducted with a variety of surface roughness configurations and wind speeds.

2.6 Mars Pathfinder thermal couple model tests: *Gregory Wilson, Arizona State University*

The Mars Pathfinder lander carried thermal probes to monitor the atmosphere in the descent phase of the landing. However, the airflow through the lander was not known and there was concern regarding the design. Consequently, tests were run prior to launch using 1/10th and 1/5th scale models of the lander in MARSWIT to determine the flow field near the descent thermal couple location. These tests led to a redesign of the system to enable valid measurements by Pathfinder during descent.

2.7 Mars Pathfinder Windsock Tests: *Robert Sullivan, Cornell University*

"Windsocks" flown on the Pathfinder lander were designed to measure wind velocity and direction as a function of height based on vertical and horizontal deflection measurements recorded by the camera. Tests on engineering, flight, and flight spare windsocks were conducted in the Mars Surface Wind Tunnel prior to the Pathfinder launch. The laser doppler velocimeter was used to accurately measure wind velocity during the tests. The windsock deflections were calibrated at Martian atmospheric densities. The design enables measuring winds on Mars between 9 and 50 meters per second, and for determining the surface wind shear and surface roughness.

2.8 Mars Microphone wind sensor tests: *Robert Haberle, NASA-Ames Research Center*

Tests of a new type of wind sensor were conducted in the Mars Surface Wind Tunnel as part of the Mars Surveyor 98 lander proposal. The Mars Microphone wind sensor enables wind velocity determinations by measuring the speed of a propagating sound wave into the wind and subtracting the speed of sound. Although the instrument was not selected, this was the first time that this type wind sensor was tested under Martian conditions, and provided the possibility that such a wind sensor might be used in the future.

2.9 Wind Flow over Seif Dune: *Gregory Wilson, Ariz. State Univ. and Haim Tsoar, Ben Gurion Univ.*

Exploratory experiments were conducted to investigate the apparent lack of the linear dunes on Mars. It was hypothesized that the mechanisms under which linear dunes form are not present on Mars because of the low density atmosphere. Several models were developed and tested in the Martian Surface Wind Tunnel. For the tests, new "skin friction" measuring technique was developed. The results confirm the linear dune-forming mechanisms on Earth, but further work is required for specific applications to Mars.

2.10 Mars Microphone tests: *Janet Luhman, University California/Berkeley*

Experiments in the Mars Surface Wind Tunnel that sounds could be heard in the thin Martian atmosphere. Form a recording made during the tests (theme music to the movie 2001), the Planetary Society sponsored the development of the microphone listening device that will fly onboard the MVACS lander.

2.11 Mars Pathfinder pressure sensor model tests: *Rachael Coquilla, University of California/Davis*

During the entry of Mars Pathfinder into the atmosphere of Mars, a pressure measuring system monitored the atmosphere. Similar to the measurement of atmosphere temperature, (see above), flow field experiments in the Martian Surface Wind Tunnel. The 1/5th scale Pathfinder model was used to determine the coefficient of pressure (C_p , local pressure divided by the total actual pressure) at the inlet of the pressure sensor in the descent configuration. These results indicated that a significant correction needs to be made to understand the Pathfinder descent pressure measurements. The results are being used to correct the Pathfinder measurements.

3.0 Facilities

In the early 1970s, a series of simple wind tunnel experiments was conducted at NASA-Ames Research Center to gain insight into the nature of aeolian activity as a planetary process. Initial results were promising and provided clues to the nature of the Martian wind streaks that were observed on Mariner 9 images. A successful proposal was submitted to NASA Headquarters to establish a facility capable of conducting experiments dealing with the physics and geology of Martian aeolian features and processes. The design, construction, and operation of the facility was undertaken by a group of planetary scientists, fluid mechanists, and engineers, led by Greeley. When Greeley left Ames in 1977, an agreement was reached among NASA Headquarters, Ames Research Center, and Arizona State University (ASU) that enabled continued operation of the facility through ASU. The facility is currently administered by the Planetary Systems Branch, Space Science Division, and is operated by ASU personnel.

PAF is located in the Structural Dynamics Building (N-242) at Ames and consists of an environmental chamber and a control room/office. The chamber was used in the early 1960s for static testing of rockets. It is 4000m³ and can be evacuated to 3.0 mb pressure in about 45 minutes. Originally, the chamber was outfitted with 'shake tables' and infrared heaters for testing full-size rockets under space conditions. The facility had been 'mothballed' by the time of the Mars proposal and it was recommissioned for the Planetary Aeolian Facility (PAF).

The PAF chamber is connected to the Thermal Protection Laboratory Boiler (Steam Plant), located in another building. The Steam Plant is a 5-stage steam-injection system fired by natural gas, and it serves several facilities at Ames. Because of the high cost to operate the Steam Plant an agreement was struck in which PAF draws its vacuum only as a ride-along with other users and at no cost to the Planetary Program.

3.1 Mars Surface Wind Tunnel (MARSWIT)

MARSWIT was put into operation in 1976. It is a 13-m long open-circuit boundary-layer wind tunnel that operates at atmospheric pressures ranging from 1 bar to 3.0 mb and at speeds as high as 100 m/sec. The test fluids can be air, carbon dioxide, or nitrogen. The test section measures 1.2 m wide, 16 m long, and 1.2 m high and is constructed of 1 inch Plexiglas to enable observation and filming/videoing during the experiments.

MARSWIT is used to investigate the physics of particle entrainment by the wind under terrestrial and Martian conditions, conduct flow-field modeling experiments to assess wind erosion and deposition on scales ranging from small rocks to landforms (scaled) such as craters, and to test spacecraft instruments and other components under Martian atmospheric conditions.

3.2 Venus Wind Tunnel (VWT)

VWT is a closed-circuit, boundary-layer tunnel measuring 6 by 2.3 m that operates with CO₂ or N₂ from 1 bar to a maximum pressure of 35 bars, producing the same fluid density at ambient laboratory temperatures as the Venusian atmosphere at 90 bars and 735 K. It is used to study particle motion and bedform development appropriate for Venus. This system has been deactivated.

3.3 Venus Aeolian Abrasion Device (VAAD)

VAAD is an apparatus used to study the abrasion of rocks and other materials by windblown particles in the Venusian environment. It is capable of operating with a carbon dioxide atmosphere from 6 to 120 bar pressure and up to 750 K temperature. Particles of given size and composition are propelled against targets under controlled conditions. The mechanical and chemical changes are assessed for both the particles and the target for application to Venus. This system has been deactivated.

3.4 Instrumentation

Differential pressure transducers (Setra System 239) are used for measuring free-stream wind velocities and deriving wind profiles. A high precision Setra differential transducer is used for measuring very low velocities. One Setra 270 Barometer, one Setra 204 0-15 PSIA transducer and one Tavis P-4AS 0-0.36 PSIA transducer are used for measuring Earth, (1 bar) intermediate, and Martian (~3.0 m) chamber pressures respectively. The chamber is equipped with 24 type T thermocouples for measuring temperature. During experiments of particle threshold and flux, particle movement is determined by charged particles hitting an electrometer plate in the wind tunnel and measured on a Keithley 602 Solid State Electrometer.

The PAF laboratory recently acquired a high-speed (500k samples/s) analog-to-digital data acquisition system from National Instruments, Inc. Running on a 100 MHz Pentium PC, the system is capable of simultaneously measuring 64 analog channels, which can be independently accessed. This system is controlled by National Instruments software package *Lab View*. This system allows for the simultaneous acquisition, analysis, and visualization of wind tunnel temperature, pressure, velocity, and electrometer probe data. Other analog and digital instruments can be incorporated to suit experimental requirements.

The PAF chamber is fitted with a TSI Inc. two component Laser Doppler anemometer (LDV). It consists of a 100 mW Argon 457-529 nm laser, beam separator-photomultiplier, digital burst correlator, fiber optic probe, and two-axis traverse table.

The dynamic range covers low (cm/s) to supersonic velocities at all atmospheric pressures. Velocity measurements are made when a particle moves through the measurement volume created by crossing of two laser beams. The crossed beams create a fringe pattern. When disrupted by the particle, two separate Doppler shifts occur. The difference in the two signals is proportional to the particle velocity.

4.0 Negative Inventions Statement

There were no inventions on this project.